NASA/TM—2004–213393

X-Ray Calibration Facility/Advanced Video Guidance Sensor Test

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September 2004

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National Aeronautics and
Space Administration

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LIST OF ACRONYMS

AOS	advanced optical system
A/V	ambient/vacuum
AVGS	advanced video guidance sensor
DART	demonstration for autonomous rendezvous technology
DSP	digital signal processor
FP2	final prototype No. 2
GN&C	guidance, navigation, and control
LRT	long-range target
MSFC	Marshall Space Flight Center
MUBLCOM	multiple beam beyond line-of-sight communications
OSC	Orbital Space Corporation
SN2	serial No. 2
SRT	short-range target
TQCM	temperature-controlled quartz crystal microbalance
VGS	video guidance sensor
XRCF	X-Ray Calibration facility

TECHNICAL MEMORANDUM

X-RAY CALIBRATION FACILITY/ADVANCED VIDEO GUIDANCE SENSOR TEST

1. INTRODUCTION

During the flight of STS–87 in November 1997, the video guidance sensor (VGS) was tested on orbit. Overall, the sensor had good results; yet, one significant anomaly was the reduced spot size on the return from the target. As the second-generation VGS—the advanced video guidance sensor (AVGS)—was being built, a concern that the anomaly would repeat led to a request for vacuum testing of the AVGS and a target at various ranges. This request took the form of a review item discrepancy initiated on September 16, 2002, at the demonstration for autonomous rendezvous technology (DART) critical design review. As an added benefit, the testing would be used to provide ambient versus vacuum noise data for input into statistical models. This Technical Memorandum addresses the vacuum testing of the AVGS in the X-Ray Calibration facility (XRCF) at Marshall Space Flight Center (MSFC), Huntsville, Alabama.

2. ADVANCED VIDEO GUIDANCE SENSOR

The AVGS is a sensor designed to acquire and track one or more targets at ranges from 1/2-m to 300 m. The sensor tracks targets that consist of corner-cube retroreflectors with a filter that passes 850 nm light and absorbs 800 nm light. The multiple beam beyond line-of-sight communications (MUBLCOM) target configuration—the target on the DART mission—has both a long-range target (LRT) and a short-range target (SRT), each of which has three retroreflectors in a line with the center retroreflector mounted on a pole. The pole allows small target pitch and yaw angles to be measured accurately.

In operation, the sensor illuminates the target with 850 nm light and takes a picture, and then illuminates the target with 800 nm light and takes another picture. The 800-nm illuminated picture is subtracted from the 850-nm illuminated picture, and a threshold is subtracted from that value to leave pixels that mostly belong to the retroreflective target (see fig. 1). These target spots are processed, and the information from the spots is used to compute the relative position and attitude between the target and the sensor. This information is sent out through a serial data port. The operation of the sensor is described in more detail in some papers on the previous sensor, the VGS.[1–3] The AVGS was designed to track targets up to a 50-Hz internal rate, but to save power, there are two tracking rates: (1) Track mode, with a 5-Hz output and a 10-Hz internal tracking rate and (2) fast track mode, with a 25-Hz output and a 50-Hz internal tracking rate.

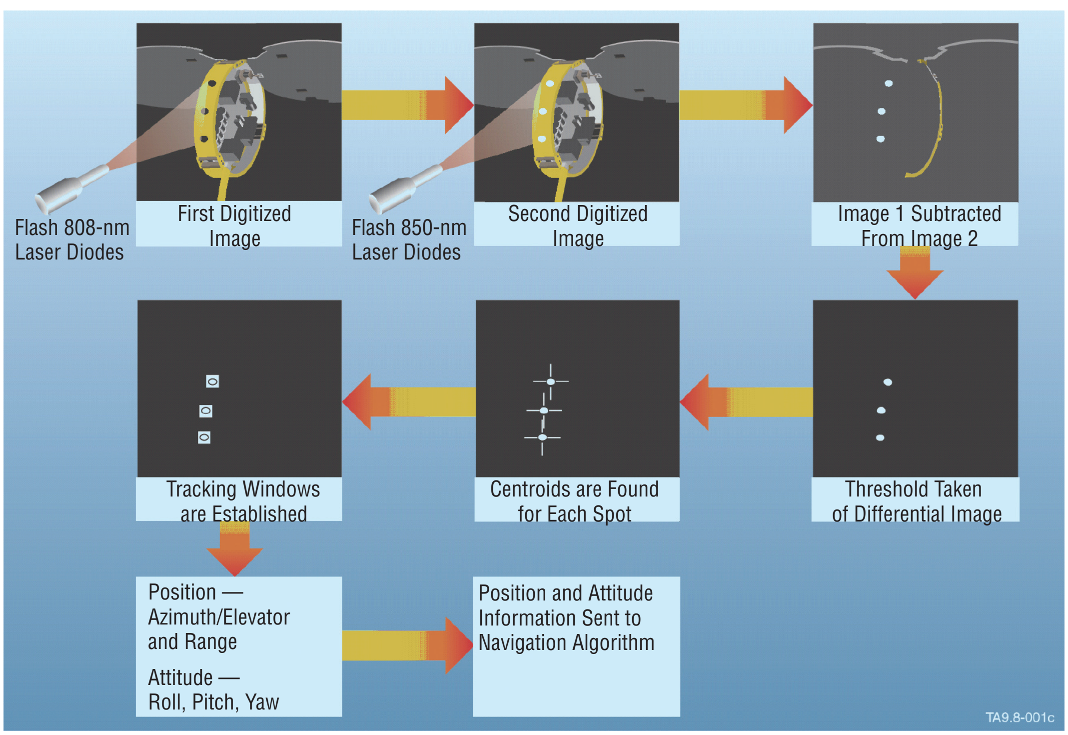

Figure 1. General processing flow of the AVGS.

The sensor has six modes of operation: Standby, acquisition, track, spot, reset, and diagnostic. In nominal operation, the unit will be in track mode for most of the time. The sensor uses two digital signal processors (DSPs) to perform the image processing and timing, housekeeping, and input/output functions. These DSPs are supported by other chips that provide interprocessor communications, frame grabbing, and image preprocessing. Figure 2 shows the AVGS's interior of the initial prototype.

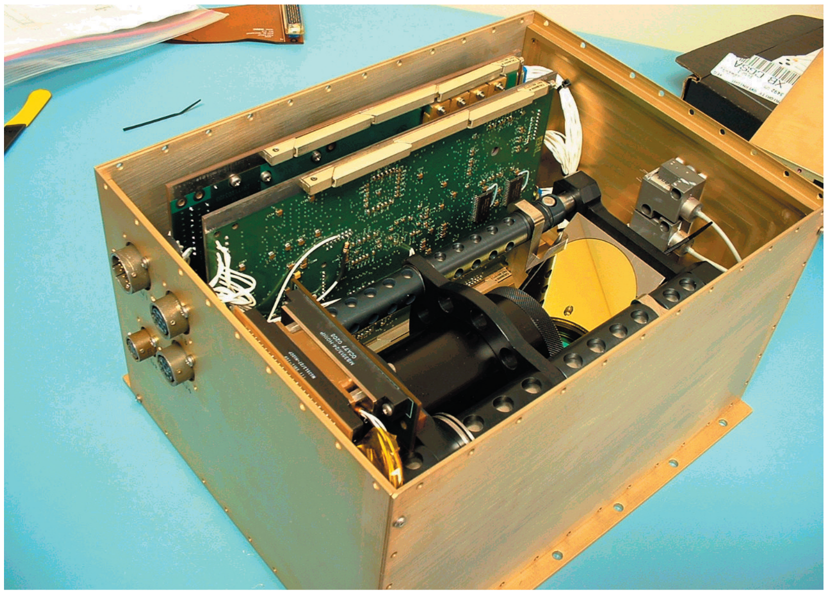

Figure 2. Interior of the initial prototype of the AVGS.

3. X-RAY CALIBRATION FACILITY

The test was conducted in MSFC's XRCF. This is a unique world-class facility that consists of an optically clean, thermally controlled vacuum chamber 22.9 m (75 ft) long and 7.3 m (24 ft) in diameter and a 518-m (1,700-ft) vacuum tube, with 3-, 4-, and 5-ft-diameter sections, which connects an x-ray source to the vacuum chamber. The vacuum chamber has liquid nitrogen panels and heater panels for environmental control and to maintain thermal stability. The tube can also be evacuated to 10^{-5} Torr or less. The vacuum chamber, east and west sections of the guide tube, and x-ray source can be isolated from each other by gate valves. It is the only facility where the AVGS could conduct long-range vacuum testing. For the AVGS, only a portion of the facility (the guide tube) was used. However, the vacuum chamber at the east end of the tube could have been used for extended range, but a special fixture would have been needed. Gate valves in the tube allowed the AVGS end to be isolated from other work activities. The XRCF successfully calibrated the Chandra high-resolution mirror assembly and science instruments in 1996–1997. Figure 3 shows an aerial view of the facility. Figure 4 shows a schematic layout of the guide tube and the approximate AVGS target locations used for testing, while figure 5 shows the building where the sensor was located (inside the tube).

Figure 3. Aerial view of the XRCF.

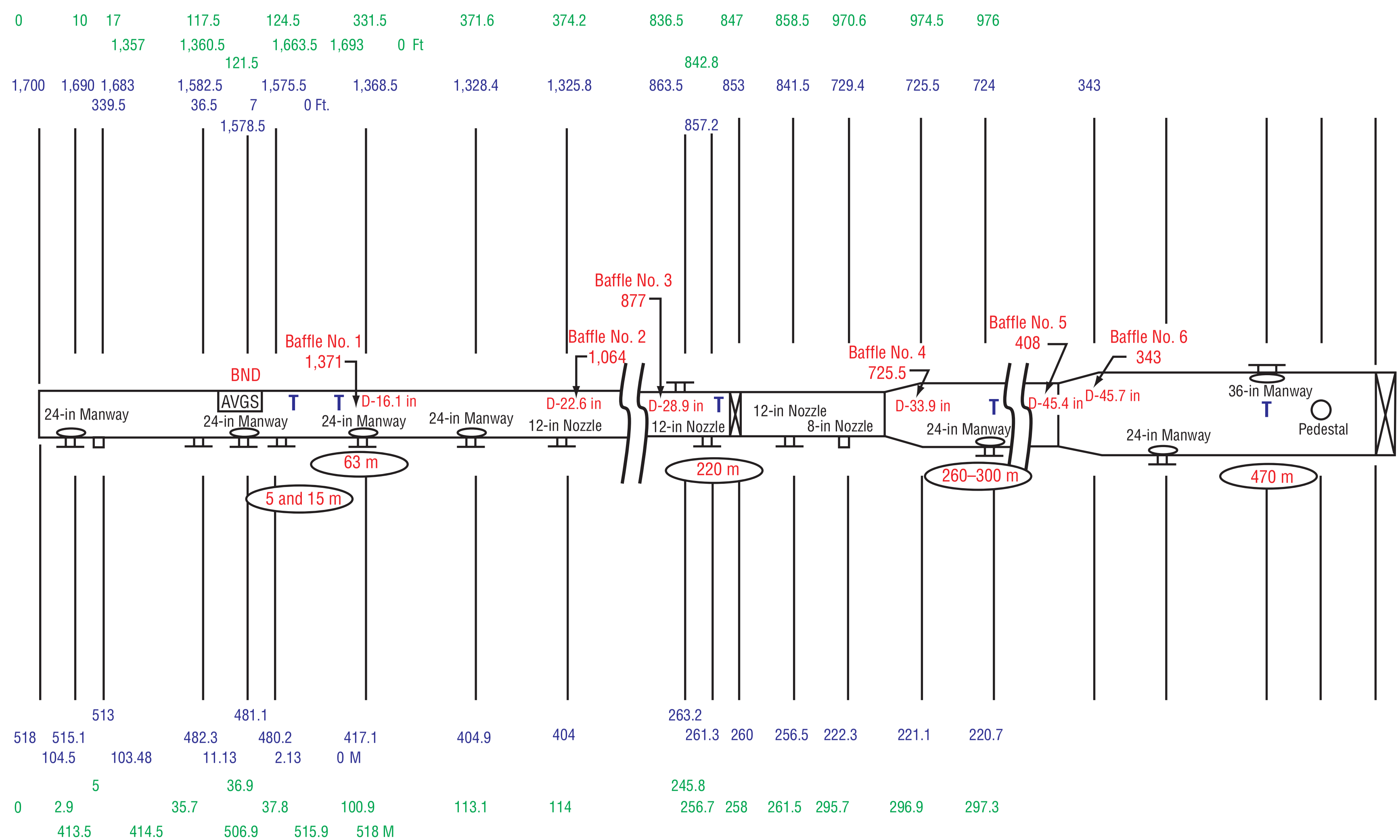

Figure 4. AVGS test layout.

Figure 5. AVGS test building.

3.1 Advanced Video Guidance Sensor Mounting Hardware

The AVGS was mounted onto an alignment fixture and then mounted to a fixed structure in the facility guide tube. The fixed structure provided a stable mount point to the guide tube while the alignment fixture permitted alignment of the AVGS facility optical axis while also providing a ±8° pitch and yaw capability. Figure 6 shows the design of the alignment fixture.

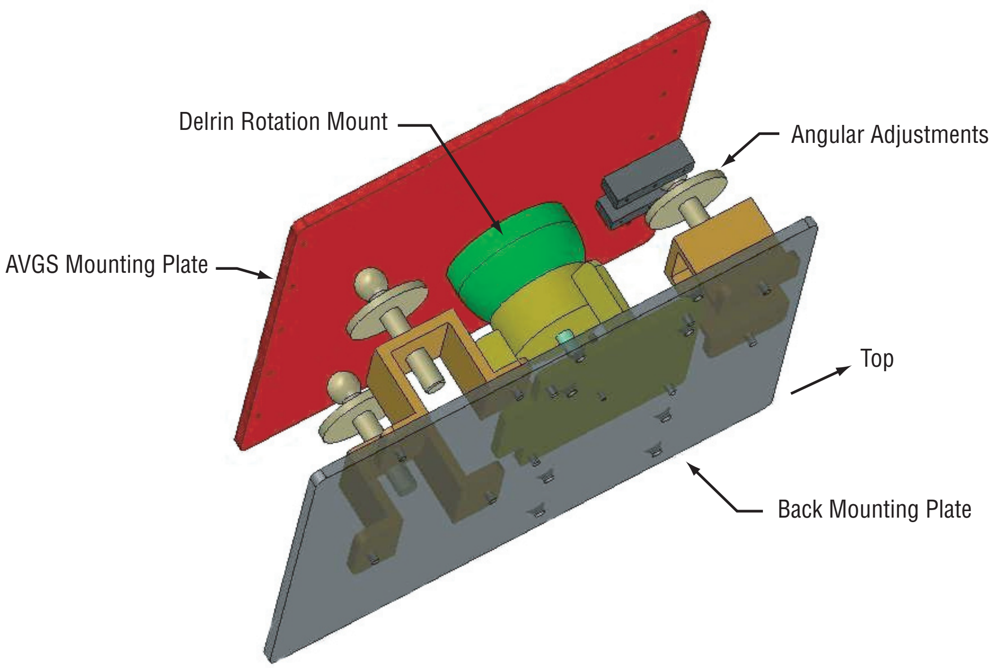

Figure 6. Tucker test fixture.

The Tucker test fixture is the AVGS mounting fixture. It consists of an aluminum plate hard-mounted to a machined delrin hemisphere that was positioned so that the center of the hemisphere was located directly behind the center of the AVGS optical window. Three manual adjustments—one above and two below, and equidistant from the center of rotation of the delrin ball—permitted ±8° pitch and yaw adjustments about the center of the AVGS optical window. The delrin hemisphere and the manual adjustments are mounted to a back plate that in turn mounts to a fixed structure hard-mounted to the facility guide tube. Figures 7–9 illustrate the mounting hardware and AVGS.

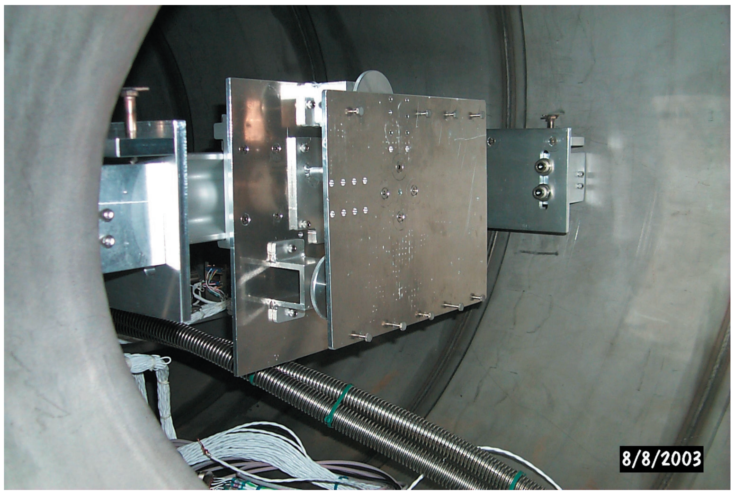

Figure 7. AVGS mounting hardware in the guide tube.

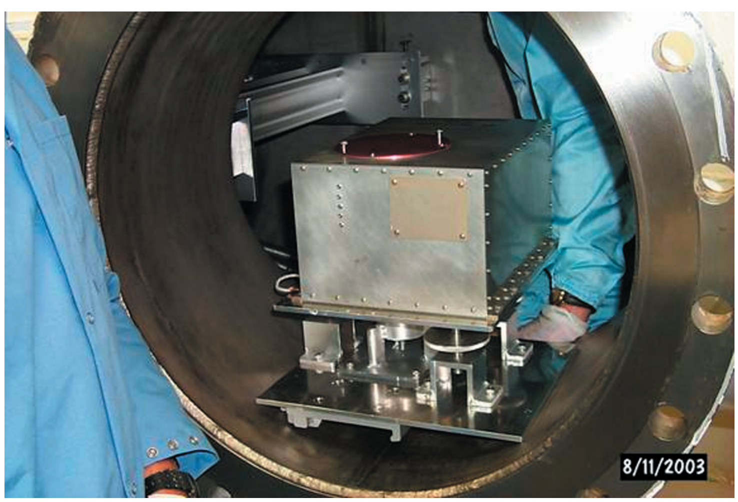

Figure 8. AVGS/Tucker test fixture assembly inside XRCF tube (before mounting).

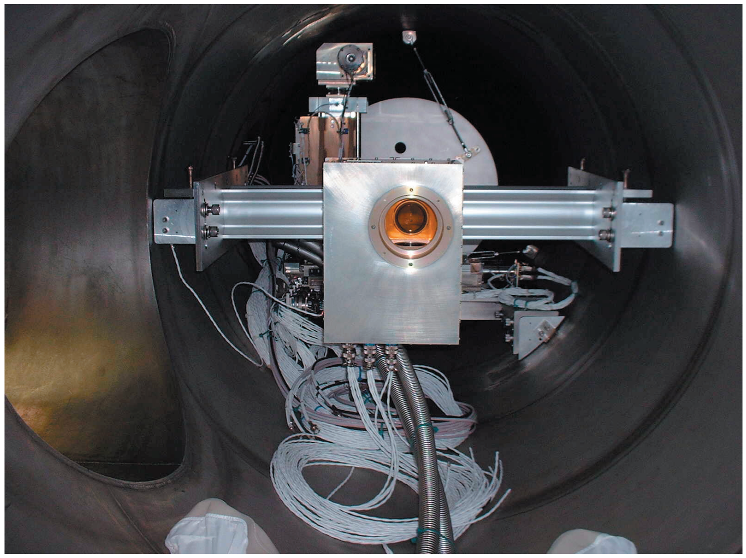

Figure 9. AVGS assembly in guide tube.

3.2 X-Ray Calibration Facility Target

The target used in the XRCF testing was different than the MUBLCOM target. Black-painted and vacuum-baked aluminum channel was used, with three retroreflectors mounted inside (figs. 10–12). A curved piece of aluminum was fitted onto the top and bottom, with the radius of the curvature being greater than the tube. As the target was set in place, a thumbscrew pushed the curved metal pieces flat against the tube and wedged the target solidly in place (figs. 13–15). For larger diameter sections of the tube, standoffs were placed on the curved pieces (fig. 16). Basically, the middle retroreflector pole, or standoff, was not used, with the effect that all three targets were coplanar. There were several reasons for this:

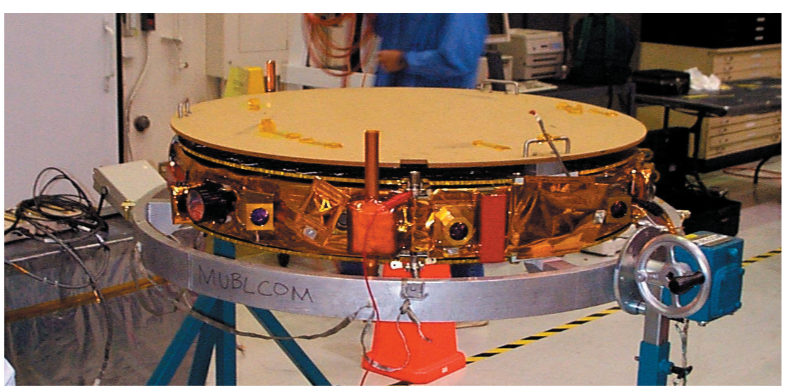

Figure 10. MUBLCOM.

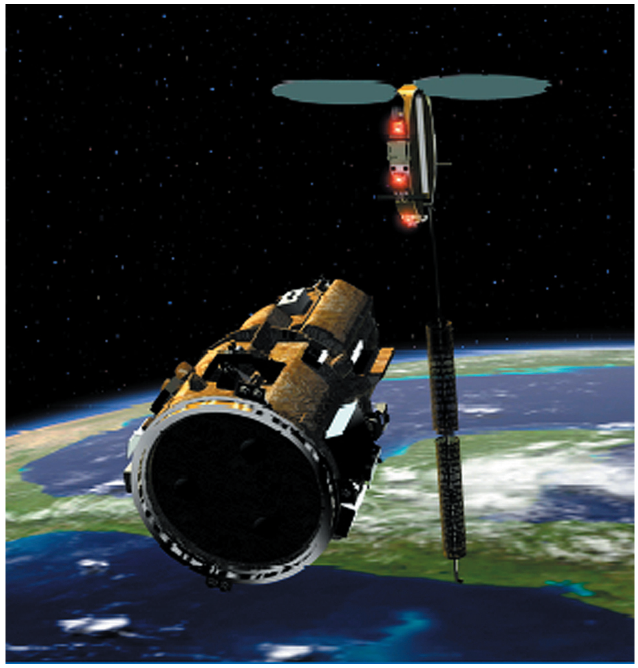

Figure 11. Picture from orbital DART fact sheet: http://www.orbital.com/NewsInfo/Publications/DART.pdf.

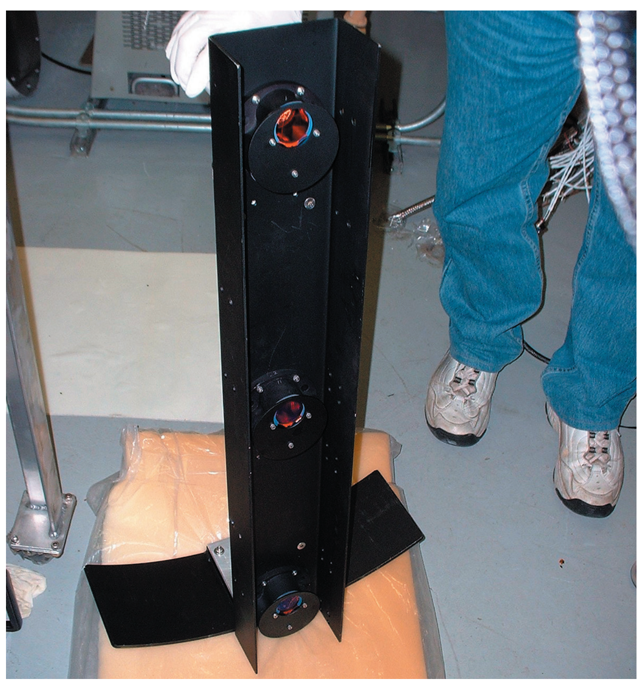

Figure 12. Note the top curved piece removed for clarity.

Figure 13. View of adjustment screw with focus target.

Figure 14. Detail of adjustment screw.

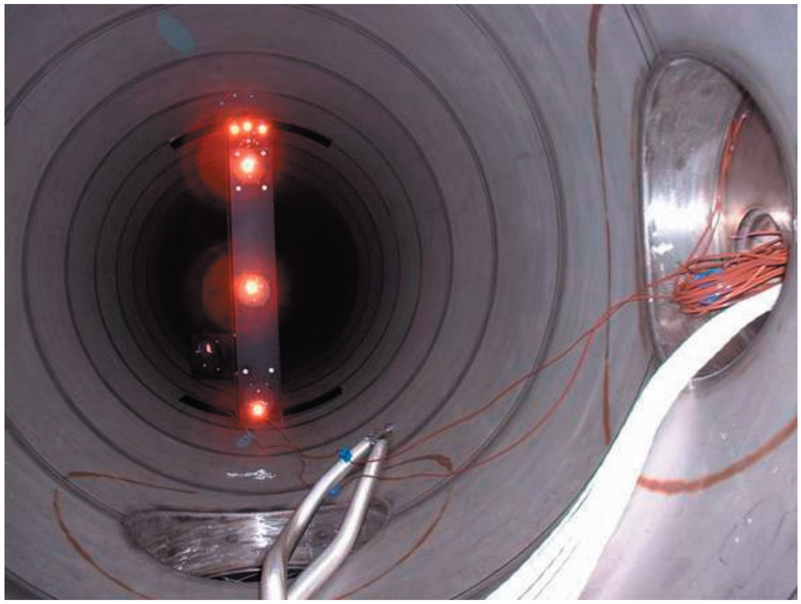

Figure 15. AVGS target assembly inside XRCF tube, LRTs and SRTs.

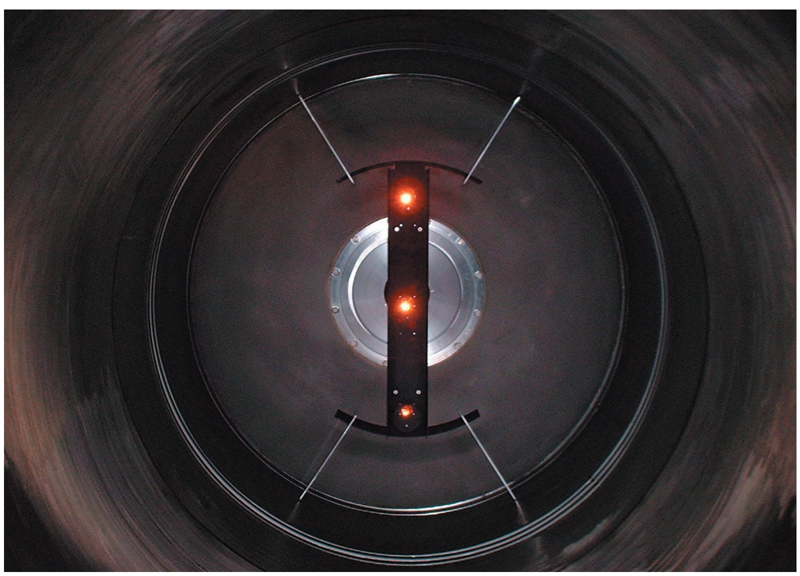

Figure 16. Extensions on target (482 m).

- The target was not required to be pitched, yawed, or rolled. Since the target would be essentially “dead-on” down the tube, the standoff would serve no purpose. However, when the FP2 requirements matured, a yaw position was thought necessary so a separate wedge was added to the target (fig. 17).

Figure 17. FP2 target with wedges.

- It was thought that if the retroreflector was extended on a boom, it might be hard to put inside the tube though a connector passthrough.

- It might be better if the retroreflectors were protected by the channel. However,

  – Even though the target is aligned dead-on down the tube, the AVGS is so sensitive it can detect minute differences in the target. Without the standoff, the AVGS outputs what it believes to be the target attitude, which is not zero pitch, zero yaw, or zero roll.

  – The XRCF was entered through a manway, so there would have been room for the pole. Also, XRCF personnel could have simply mounted the center retroreflector after placing the target.

  – Mounting procedures were safe enough to not pose a hazard to the tube or personnel.

The retroreflectors used in the target channel were the standard AVGS LRTs. An SRT was added to the top of the channel (fig. 15) for the initial testing (with FP2), and for the 5-m testing for the serial No. 2 (SN2). An unfiltered target was also experimented with (the top target in fig. 17).

In the future, adding the center standoff for the retroreflector is recommended.

4. FINAL PROTOTYPE NUMBER 2 TIMELINE (2003)

The first AVGS tested in the XRCF was the final prototype No. 2 (FP2), a sensor developed by Orbital Space Corporation (OSC) for software development. The sensor was to be tested at the following ranges: 1, 5, 15, 63, 208, and 300 m with various positions and targets. The following timeline documents the history of testing FP2 in the XRCF (see appendix for explanation of target configurations):

- 8/1 (Friday)

XRCF procedures required the AVGS and targets to be cleaned and vacuum baked prior to insertion into the XRCF. To meet this requirement, all hardware, excluding optical surfaces, was cleaned with 200-proof ethyl alcohol and placed into the bakeout chamber. The bakeout requirement was 65 °C (149 °F) for 24 hr at 10^{-5} Torr or better with a temperature-controlled quartz crystal microbalance (TQCM) measurement of <1 Hz/hr at 35 °C (95 °F) at 10^{-5} Torr or better. The AVGS sensor was not powered during bakeout.

- 8/2 (Saturday)

AVGS was under bakeout conditions of 1.9×10^{-6} Torr, 65 °C (150 °F).

- 8/3 (Sunday)

A facility power failure occurred at approximately 5:47 p.m. The AVGS was at 66 °C (151 °F), 1.21×10^{-6} Torr. Power was restored at approximately 7:28 p.m. Data collection restarted at 38 °C (101 °F), 5.4×10^{-1} Torr. Bakeout was extended to compensate.

- 8/4 (Monday)

AVGS bakeout stopped.

- 8/5 (Tuesday)

AVGS was moved to TQCM chamber and the process was started.

- 8/6 (Wednesday)

A second facility power failure occurred after 9:00 a.m. TQCM was restarted.

- 8/7 (Thursday)

TQCM completed at 8:00 a.m. and the AVGS sensor was removed from the chamber. The 12-hr delta was 0.132 Hz/hr. An AVGS laser power-up test failure occurred (laser output voltage had dropped significantly) but a decision was made to proceed with testing to get whatever data were possible.

A “ghosting” problem was noted for the first time during the postbake checkout. (“Ghosting” is seeing spots where they should not be.)

- 8/8 (Friday)

AVGS was moved to the XRCF and installation was begun.

- 8/11 (Monday)

The AVGS sensor was placed in the XRCF tube and the target was positioned at 5 m, configuration N1 (SRT, three LRTs, and LRT wedge mirror). The XRCF test readiness review was completed. The first ambient 5-m test and first vacuum 5-m test were run using software version 1.5a. Due to the likelihood of laser failure, the planned laser power repeatability tests were not run.

- 8/12 (Tuesday)

The second 5-m ambient test was completed. A spot size difference between vacuum and ambient conditions was observed. This was quite possibly due to factors other than vacuum.

- 8/13 (Wednesday)

A 4- and 3.2-m testing run using configuration N1 was completed to satisfy Advanced Optical Systems’ (AOS’) request to see targets at the edges of the field of view. Data from the post 3.2-m laser checkout were lost due to a keyboard failure.

- 8/14 (Thursday)

Still using software version 1.5a, 1-m ambient and 1-m vacuum tests were run with configuration M (SRT only in center of channel) target set. Repeatability tests were not run due to expected laser failure. Another 1-m vacuum test was run with new flight code version 1.5c, but no new algorithms were added.

- 8/15 (Friday)

The first full data sets, including laser repeatability, were collected at the 1-m ambient condition using target configuration M. After receiving permission to move targets to 208 m, more unsuccessful attempts were made to mask reflections noted in the background picture.

- 8/18 (Monday)

The target in the T1 configuration (two LRTs in channel) was moved to the 208-m range. Range was verified using the retroreflector target with DME3000 laser rangefinder. A visual inspection of the target-to-sensor geometry indicated that some XRCF tube baffles might block the return signal. To investigate this possibility without actually removing the baffles, spot sizes using several target configurations were analyzed. Since no definite conclusion was obtained from the experiments, a decision was made to remove the three sets of baffles to 208 m.

- 8/19 (Tuesday)

The 208 occlusion test was run using configuration T3 and N3 (three LRTs) at 208 m under ambient conditions with baffles removed. The spot size still varied greatly. Variation in spot size was probably large enough to likely overwhelm any changes directly due to ambient versus vacuum conditions.

- 8/20 (Wednesday)

Ran two 208-m vacuum tests (for comparison) and went into a hold to discuss possibility of thermal variation affecting spot size.

- 8/21 (Thursday)

Ran the 208-m vacuum temperature test. Collected spot data every 30 min. Still saw spot variation when the internal AVGS temperatures seemed fairly constant (within a few degrees).

- 8/22 (Friday)

With the target in the N3 configuration, the postvacuum 208-m ambient and the 208-m, –7° pitch ambient tests were run.

- 8/25 (Monday)

The vacuum 208-m, –7° pitch and the second 208-m, –7° pitch ambient tests were run. (Note: Saw spots in postambient test data 3 to 4 times vacuum size.)

- 8/26 (Tuesday)

Ran the ambient 208-m, –7° pitch, 7° azimuthal test. Many anomalies, including intermittent tracking losses and potentially a reflection noticed for the first time by the test conductor, were noted.

- 8/27 (Wednesday)

Ran the vacuum 208-m, –7° pitch, 7° azimuthal and the postvacuum ambient tests. Intermittent tracking failures were noted once again.

- 8/28 (Thursday)

Using the N4 target configuration (two targets mounted on wedges on opposite sides of channel, unfiltered on top), the "Ricky Howard" tilt test (208-m, –7° yaw and pitch of –7°, 0°, and 7°). The 208-m wedge test was not completed because the data were odd. An unfiltered target seemed to be visible when it should not have been, and reflections also appeared to be visible from a new angle.

- 8/29 (Friday)

Reran canted target ambient 208-m (after postdata analysis from 8/28) and 300 ambient tests straight on. (Note: Saw all three spots, and tracked at 300 intermittently. The range was way off.)

- 9/1 (Monday)

  Holiday.

- 9/2 (Tuesday)

  The XRCF was reconfigured for the 300-m vacuum run.

- 9/3 (Wednesday)

  Made the first 300-m vacuum run using configuration N3 and flight code 1.5c. Software load 1.5d was attempted but failed.

- 9/4 (Thursday)

  300-m ambient run (flight code 1.5c). Software load 1.5d was attempted but failed again. Never saw acquire mode go to track mode (hard time getting three spots). AVGS was removed from the XRCF.

5. RESULTS

FP2 had significant problems during testing. The laser output was too low at the start. A range anomaly led to discovery of a cosine error in the firmware. Another problem was the large variation in spot size over time. Posttest analysis lead to the discovery that a dual-pass solar filter used in the optical barrel did not have the response range that was needed. A broadband solar filter was substituted. Also, some odd thermal readings lead to the discovery that a coldfinger (a thermal strap) had become separated from the imager. Hazing was discovered on one of the lenses, possibly caused during bakeout. It was also discovered the original bake temperature was too high—revealed by manufacturer after test.

Since there were so many anomalies with FP2, and since another, more flightlike AVGS became available, the data analysis team recommended a second test with SN2.

6. SERIAL NUMBER 2 TIMELINE (2004)

The following timeline documents the history of testing SN2 in the XRCF:

- 2/25 (Wednesday)

AVGS TQCM begins. The AVGS was cleaned and placed into the XRCF thermal vacuum chamber. All hardware, excluding optical surfaces, was cleaned with 200-proof ethyl alcohol and placed into the bakeout chamber. The bakeout requirement was 40 °C (104 °F) for 2.5 hr at 10^{-4} Torr or better with a TQCM measurement at a flat rate of change at 10 °C (50 °F) at 10^{-5} Torr or better. The AVGS was not powered during bakeout. An absolute TQCM standard was not used due to background concerns on the thermal vacuum chamber. Also, the bake criteria differed from the original FP2 requirements since the SN2 had been previously baked.

- 2/26 (Thursday)

AVGS TQCM passed (delta frequency was <1 Hz/hr for the last 8 hr).

- 2/27 (Friday)

Connector bakeout at 80 °C (176 °F) for 72 hr. (These were cable savers used to protect AVGS pins.)

- 3/1 (Monday)

AVGS installation in XRCF, temperature sensors mounted on box, safe to mate test, focus test at 50 m. The focus test was used to ensure the focus of the AVGS had not changed. This test indicated a slight focus shift had occurred. The reason for this change is under investigation.

- 3/2 (Tuesday)

Laser power focus test, a laser power check at different foreground and background laser powers for comparison to the previous baseline, was performed because of the believed focus shift.

- 3/3 (Wednesday)

2-m focus test, a more detailed check of the focus, AVGS was passed by and the test proceeded. 482-m ambient run was started.

- 3/4 (Thursday)

482-m vacuum run with three spots, then with two spots. (The center spot was covered to give a retroreflector separation of 28 in instead of 14 in.) This test would give an indication of sensor range with a different target.

- 3/5 (Friday)

Postvacuum run with two spots, then with all three spots. Target was moved to 300 m. 300-m ambient test, 300-m vacuum.

- 3/8 (Monday)

300-m postvacuum, and then target was moved to 200 m. 200-m ambient, 200-m vacuum, 200-m postvacuum.

- 3/9 (Tuesday)

Second 200-m postvacuum. (This second test was an attempt to ascertain why a spot was missing; see below). Laser power check due to anomaly; see below. Move to 15 m and conducted that ambient run.

- 3/10 (Wednesday)

Second 15-m ambient run to evaluate laser power anomaly, 15-m vacuum, 15-m postvacuum, move target and conducted 5-m ambient.

- 3/11 (Thursday)

Second 5-m ambient run to evaluate laser power anomaly, 5-m vacuum, 5-m postvacuum.

- 3/12 (Friday)

Remove AVGS.

7. MAJOR X-RAY CALIBRATION FACILITY ANOMALIES

7.1 Missing Spot

On March 8—for the first ambient test only—two spots were seen (fig. 18). At that time, it was believed that a baffle had interfered with the top spot and the test proceeded. During the vacuum and postvacuum testing, the spot reappeared. It is believed that thermal contraction of the baffle had occurred to hide the spot, since the tests where it reappeared were later in the day. Another ambient test was run the next morning in cooler conditions to demonstrate that the spot would be hidden again; the spot was still visible! (See fig. 19.)

Figure 18. 200-m ambient case.

Figure 19. 200-m second postvacuum.

Later analysis showed that a small pitch in the sensor combined with the minute shift in the target's center reference to the imager would account for the missing spot. However, this is not conclusive. Other theories range from a temporary vacuum in the target, creating a lensing effect to refraction caused by temperature differences. (See the refraction section below.) Temporary condensation of the air was considered and eliminated when learned the replenishment air in the XRCF has a dewpoint temperature of less than –38 °C (–100 °F). (XRCF does keep these records and the air has been verified). Condensation from the target was considered and eliminated since the target had undergone a previous vacuum episode and had been kept in the XRCF dry air. For further testing, the target should simply be moved farther from the baffle to eliminate these problems.

7.2 Laser Power Anomaly

Another problem occurred at the 200-m testing. During the morning of March 9, the laser output appeared to suffer a loss of power. Subsequent testing revealed one of the background lasers would shut off at full power if the temperature was cold. The effect seemed to go away when the box temperature approached 16 °C (60 °F). Because this was only the background laser at full power (200 or 199 counts) and the box was only seeing low temperatures (fifties) for the very early morning, the test proceeded. At 200 m, the recommend power level was 195, so the data would not have been affected. At this time, further investigation is planned by OSC to determine the cause of the failure. (See figs. 20–23.)

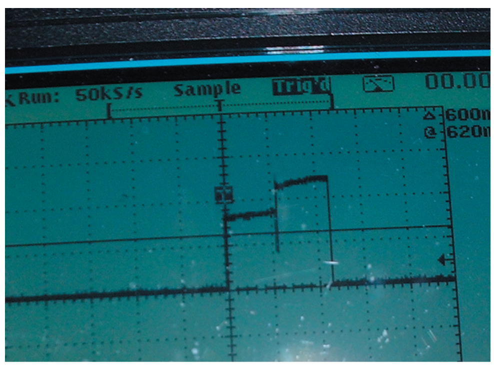

Figure 20. Normal waveform for half foreground laser power and full background laser power.

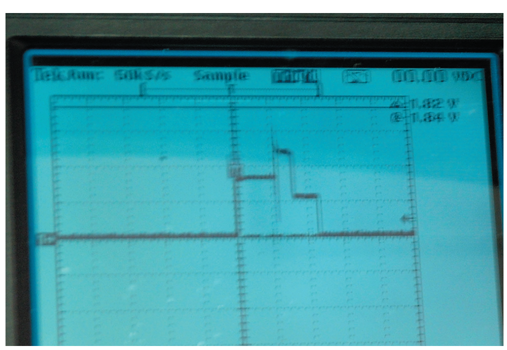

Figure 21. Output waveform of laser firing—note the third level is actually a drop in the background laser power.

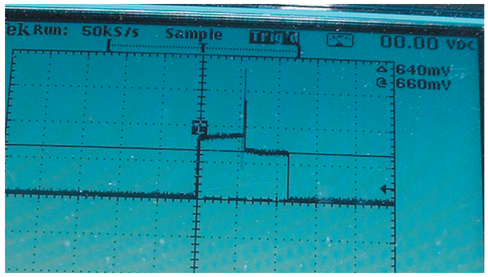

Figure 22. Another view of anomaly—note the laser is dropping power almost immediately.

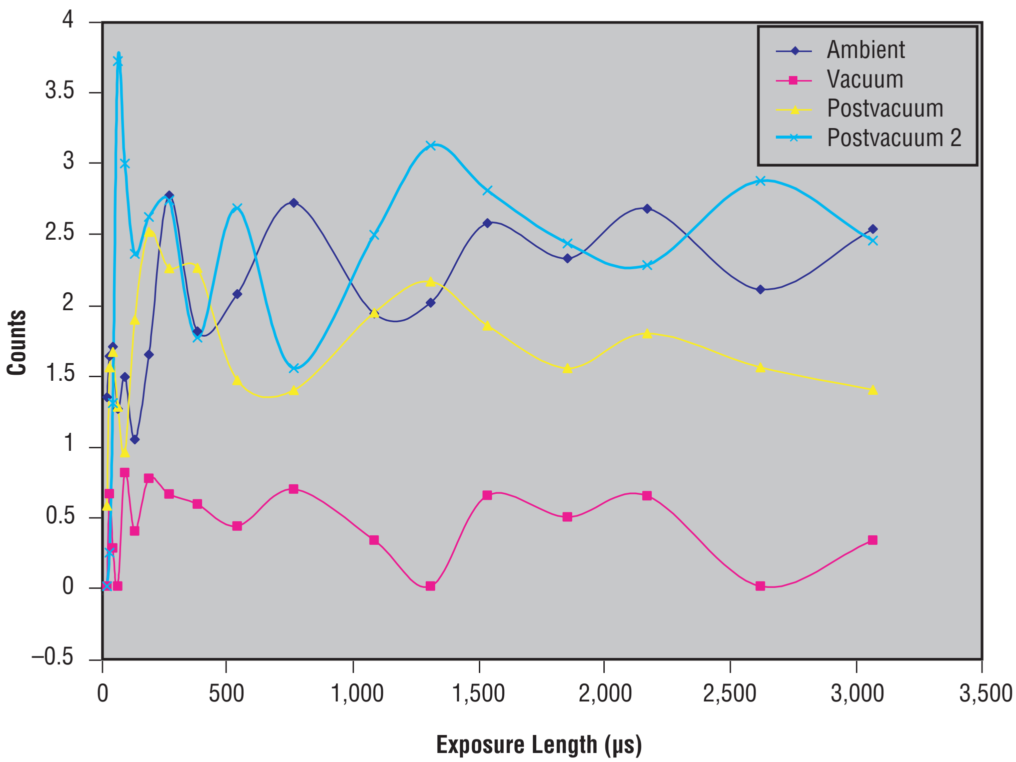

Figure 23. Spot summation number standard deviation.

7.3 Other Tube Effects

Scintillation is the rapid variation of color, brightness, or position of a luminous source. In this case, the ambient Sun shining on the tube creates strong convection currents. This effect may be seen upon evaluation of the standard deviation of the spot size. Note the vacuum has the smallest standard deviation in figure 23. This data set is from the 208-m test. (Internal sensor noise may occur for some of the remainder of the tests.)

7.4 Refraction

Because of the missing spot, an investigation was conducted into ambient temperature variations of the tube. Thermocouples were placed in the tube at various heights and positions and the data were recorded for several days. Temperature differences from the top to bottom of the tube could be nearly –8 °C (18 °F), and obvious laying was evident (fig. 24). Dr. James Carter, SD72/MSFC, analyzed the data and concluded, "This variation is more than enough to be significant in the optical response of the medium and cause light not to propagate in a straight line as one would expect but it will be deviated in a continuous manner as it traversed the medium, not in a plane. Further, with temperature variations along the tube, the same effect can be seen even in a plane in the medium."

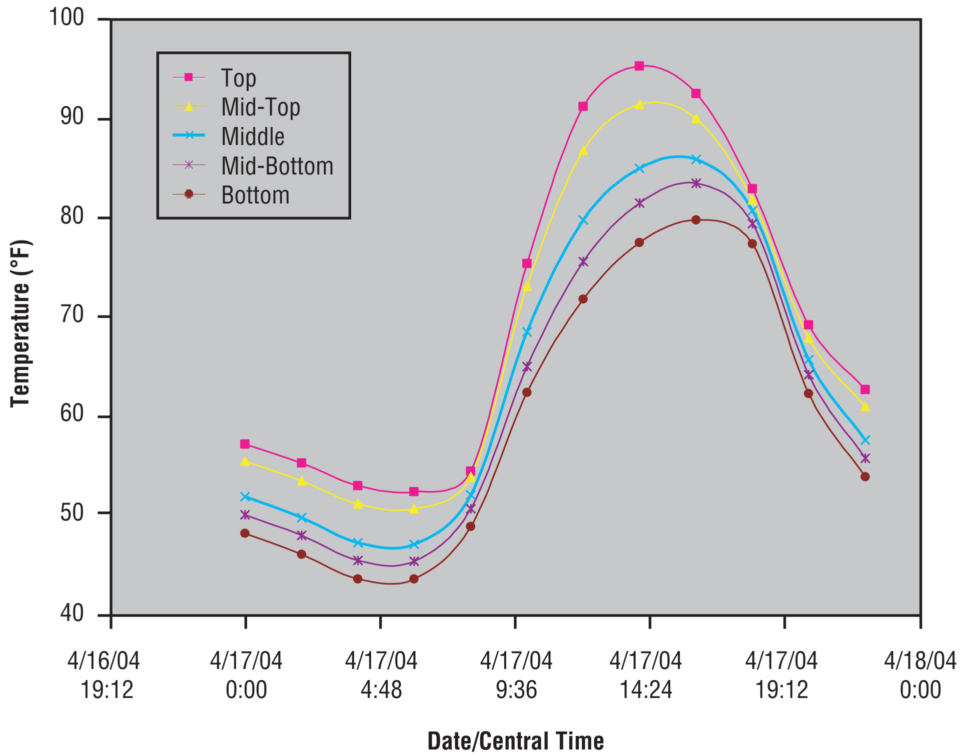

Figure 24. Spot size variation with temperature.

8. RESULTS

The purpose of the testing was twofold:

(1) Determine the output noise bias level. Table 1 delineates the DART AVGS SN2 unit's statistical measurement results from the XRCF testing. The importance of these data to the overall DART guidance, navigation, and control (GN&C) effort is twofold. It is essential in attempting to correlate ambient versus vacuum data for input into the ED19 AVGS characterization noise model and the OSC noise model used in their nonreal time simulation. Further, it is also important in providing an overall assessment of noise levels and bias errors potential impact on GN&C system performance, especially those affecting fuel consumption and the ability of the system to accurately follow the prescribed trajectories and mission profile.[4] See table 1 for results. The 482-m data were not analyzed.

Table 1. DART AVGS SN2 unit's statistical measurement results.

Date	Type	Range	TrueRange	MeasRange	Bias
4/6/04	XRCF	5	5	4.50017193	0.499828
4/6/04	XRCF	15	15	15.1822573	–0.18226
4/6/04	XRCF	200	200	198.349803	1.650197
4/6/04	XRCF	300	300	297.62527	2.37473

(2) Determine spot size change in ambient versus vacuum. Table 2 shows the percent change in spot size at close range, while table 3 gives the far-range spot size changes. Several interesting effects are seen. At minimal exposure times, a tremendous variation in spot size may be seen. In fact, the variation may be a reversal of what one might expect—that the spot size would shrink in vacuum because of the lack of atmospheric scattering. Also of interest is that the effect of ambient to vacuum appears to grow larger with range and then fall off. However, for the median exposure, one typically sees an increase of 20 percent for 5 m, 32 percent for 15 m, 19 percent for 200 m, 10 percent for 300 m, and 6 percent for 482 m. Notice the ambient/vacuum (A/V) case for 200 m is missing (reference the missing spot above). As the effect of ambient to vacuum lessens, the standard deviation also grows, until at extreme range (482 m), one cannot be sure of the effect.

Table 2. Percent reduction in spot size, close range (data points <1 count and the maximum and minimum three exposures were not used).

Ranges Exposures	5 A1/V	5 A2/V	5 P/V	5 A1/A2	15 A1/V	15 P/V	15 A2/V	15 A2/A1
6	148.33	–63.25	174.42	575.73	121.49	110.78	–78.03	–90.08
12	26.66	21.53	24.02	4.22	45.46	49.41	–57.52	–70.80
17	22.59	20.55	20.54	1.70	52.25	51.43	–38.52	–59.62
24	23.07	20.84	20.71	1.85	38.05	35.61	–27.23	–47.29
34	20.62	21.18	17.66	–0.46	37.85	39.86	–17.75	–40.33
48	20.64	18.88	17.91	1.48	37.15	34.80	–7.70	–32.70
68	20.29	20.10	18.73	0.16	30.44	27.53	–7.07	–28.76
96	19.55	18.05	17.05	1.27	30.26	30.41	–4.48	–26.67
136	20.60	17.87	18.68	2.32	31.06	28.94	–0.52	–24.10
192	20.95	18.46	19.92	2.10	28.68	23.07	–4.45	–25.74
272	22.61	15.74	24.88	5.93	25.84	25.28	–2.80	–22.76
384	27.07	13.25	32.94	12.20	28.32	25.50	–0.42	–22.40
543	29.13	12.09	35.53	15.20	26.68	23.55	–2.35	–22.92
767	28.64	13.81	29.87	13.03	–	–	–	–
Average	21.04	18.89	19.44	1.83	33.36	31.46	–9.89	–32.23
Standard Deviation	1.2	1.8	2.5	1.9	4.1	5.7	9.3	8.6

Table 3. Percent change in spot size, far range (data points <1 count and the maximum and minimum three exposures were not used).

Ranges Exposures	200 P1/V	200 P2/V	200 P2/P1	300 A/V	300 P/V	482 A/V1	482 A/V2	482 PV/V1	482 PV/V2	482 V1/V2
34	–3.04	–	–	–	–	–	–	–	–	–
48	38.76	–86.74	–323.77	–33.75	–	–	–	–	–	–
68	41.67	–31.13	–174.72	49.60	–76.27	–	–	–	–	–
96	40.56	8.42	–79.23	41.60	–39.20	80.80	10.52	–14.19	–47.55	63.59
136	29.34	4.71	–83.94	15.05	–10.86	35.05	15.08	0.00	–14.79	17.35
192	32.46	8.03	–75.26	8.70	6.30	15.74	14.54	25.57	24.27	1.04
272	22.28	4.52	–79.72	22.22	18.26	17.53	15.79	18.03	16.28	1.50
384	14.67	3.41	–76.72	14.75	8.96	16.91	12.23	–1.68	–5.60	4.16
543	14.16	0.80	–94.38	5.41	8.85	4.64	2.31	9.23	6.80	2.27
767	10.45	2.39	–77.11	15.04	18.55	7.88	6.24	11.70	10.00	1.54
1,086	13.54	6.27	–53.68	15.35	8.30	11.08	7.90	0.17	–2.70	2.95
1,311	11.78	3.42	–70.95	4.15	0.05	4.21	5.82	–1.45	0.06	–1.52
1,536	12.11	2.15	–82.26	4.96	5.88	6.44	6.35	3.84	3.74	0.09
1,854	10.72	1.83	–82.91	4.45	7.03	7.22	8.55	7.81	9.14	–1.22
2,172	13.40	3.55	–73.49	6.61	10.01	7.35	7.35	10.57	10.57	0.00
2,422	–	–	–	13.62	15.89	–	–	–	–	–
2,622	10.02	1.54	–84.64	14.73	15.96	4.55	7.04	2.55	4.99	–2.32
2,852	–	–	–	16.56	12.43	–	–	–	–	–
3,068	11.99	2.48	–79.30	–	–	–	–	–	–	–
3,072	–	–	–	14.91	7.12	5.98	6.51	–0.61	–0.12	–0.49
3,708	–	–	–	11.12	11.05	5.55	5.82	–0.26	0.00	–0.26
4,344	–	–	–	5.86	3.90	3.56	2.21	–2.11	–3.39	1.33
Average	19.28	3.75	–77.69	11.54	10.50	8.78	7.96	6.07	5.33	0.75
Standard Deviation	10.4	2.2	10.5	5.7	5.5	4.88	3.7	6.5	6.7	2.1

There were two cases that do not match our other results: The second 15-m ambient run and the 200-m postvacuum. Both of these cases were run at low temperatures (table 4). The 15-m case is especially difficult to understand since it appears that the ambient run is a smaller spot size than the vacuum. Cold, stable air should still be more scattering than no air! The 200-m case also showed a curious dimming (fig. 19). Test conductor error was considered but an analysis of the data showed the same cases in ambient and vacuum were run.

Table 4. Box temperature is from sensors mounted on the outside of the box. The guide tube temperatures came from the thermocouple located down the tube (several feet) from the box.

Test	Date	Time	Box Temperature	Outside	Tube 1	Tube 2
481.5 m						
Ambient	3/3	1446	26	23	23	24
Vacuum	3/4	0829	19	20	19	19
Postvacuum	3/5	0907	24	21	21	21
300 m						
Ambient	3/5	1047	24	27	22	23
Vacuum	3/5	1532	23	22	21	21
Postvacuum	3/8	0821	10	7	8	9
200 m						
Ambient	3/8	1039	15	10	15	16
Vacuum	3/8	1335*	20	13	19	19
Postvacuum 1	3/8	1621	19	13	16	17
Postvacuum 2	3/9	0726	9	9	9	9
15 m						
Ambient	3/9	1434	18	9	14	15
Ambient 2	3/10	0803	11	2	7	8
Vacuum	3/10	1110	17	11	18	18
Postvacuum	3/10	1509	19	12	18	18
5 m						
Ambient	3/10	1627	20	12	17	18
Ambinet 2	3/11	0834	14	10	11	12
Vacuum	3/11	1119	18	17	19	19
Postvacuum	3/11	1618	23	19	21	21

* 30-min data collection.

While the 300-m postvacuum case (fig. 25) was run at low temperature and the results matched well, the data did show some irregularities. For the postvacuum case at lower exposures, the top spot showed a curious dimming while the center widened. Again, condensation was explored as a reason and discredited due to the dryness of the XRCF replenishment air. (See the missing spot anomaly above.) There is no conclusive explanation as to what happened.

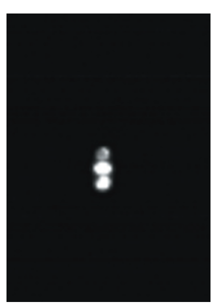

Figure 25. 300-m postvacuum.

9. CONCLUSIONS

The effects seen during XRCF testing do match those seen on orbit during VGS testing. Reduction in spot size is a real phenomena and should be considered during flight preparations. However, the reduction in atmospheric effects just makes the sensor more robust by being able to track at longer range. At close range, more attention should be paid to spot size, but the effect appears more consistent and able to be compensated for using increased laser power or longer exposure times. At extreme ranges, the sensor noise appears to mask those variances.

The XRCF is the only place to get long-range sensor performance in a vacuum. Its unique attributes make it a world-class facility and any further testing by any optical sensor should consider it. The data gathered at vacuum is suitable to model the lack of atmosphere on orbit.

There is, however, some thermal concerns—the anomalies all occurred at cold temperatures. Condensation effects are not credible as a failure mechanism. The software records exposure times, laser powers, and threshold so human error in running the test could be discovered. The cold air affected either the sensor, target, our test facility, or some combination, but exactly which is not decisively known. Additional testing of the sensor is recommended to ensure it was not the problem. The Flat Floor facility at MSFC has an oven that can be used to cool the sensor and conduct performance testing. This test should concentrate only on thermal effects; hence, the vacuum is not needed.

APPENDIX—FINAL PROTOTYPE NUMBER 2 TESTING TIMELINE TARGET CONFIGURATIONS

The following provides the reader a guide to target configurations used in the FP2 testing timeline:

- M0—the SRT mounted at the center (pole) position of the LRT. SRT mirrors perpendicular to the AVGS line of sight.
- N1—SRT mounted 3.81 in above the LRT. SRT outer mirrors aligned perpendicular to the LRT outer mirrors. An LRT mirror canted (wedged) at 25° to the AVGS line of sight and mounted to the side of the LRT.
- N2—XRCG target with LRT center mirror canted (wedged) at 25° and the side mirror is a far-range unfiltered mirror.
- N3—XRCF target with three LRTs only.
- N4—XRCF target with two side wedges, unfiltered on top, opposite sides of channel.
- T1—Two LRTs (1 and 3), center position.
- T3—All LRTs shifted up by one bolt hole.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave Blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	September 2004	Technical Memorandum

4. TITLE AND SUBTITLE

X-Ray Calibration Facility/Advanced Video Guidance Sensor Test

5. FUNDING NUMBERS

6. AUTHORS

N.A.S. Johnston, R.T. Howard, and D.W. Watson

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

George C. Marshall Space Flight Center
Marshall Space Flight Center, AL 35812

8. PERFORMING ORGANIZATION REPORT NUMBER

M–1122

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Washington, DC 20546–0001

10. SPONSORING/MONITORING AGENCY REPO NUMBER

NASA/TM—2004–213393

11. SUPPLEMENTARY NOTES

Prepared by the Avionics Department, Engineering Directorate

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Unclassified-Unlimited
Subject Category 19
Available: NASA CASI 301–621–0390

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The advanced video guidance sensor was tested in the X-Ray Calibration facility at Marshall Space Flight Center to establish performance during vacuum. Two sensors were tested and a timeline for each are presented. The sensor and test facility are discussed briefly. A new test stand was also developed. A table establishing sensor bias and spot size growth for several ranges is detailed along with testing anomalies.

14. SUBJECT TERMS

X-Ray Calibration facility, testing, advance video guidance sensor, laser, docking, rendezvous, vacuum, spot size

15. NUMBER OF PAGES

40

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18
298-102